# Automatic generation of models for abdominal aortic aneurysms and intraluminal thrombus based on hexahedral meshes

J. Tarjuelo-Gutiérrez[1,2], B. Rodriguez-Vila[1,2], P. Sánchez-González[1,2], P. Lamata[3], D.M. Pierce[4], G.A. Holzapfel[4,5], E.J. Gómez[1,2]

[1] Bioengineering and Telemedicine Centre, ETSI de Telecomunicación, Universidad Politécnica de Madrid, Madrid, Spain

[2] Networking Research Center on Bioengineering, Biomaterials and Nanomedicine (CIBER-BBN), Zaragoza, Spain

[3]Department of Computer Science, University of Oxford, Oxford, England

[4]Institute of Biomechanics, Center of Biomedical Engineering, Graz University of Technology, Graz, Austria

[5] Department of Solid Mechanics, School of Engineering Sciences, Royal Institute of Technology, Stockholm, Sweden

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## Purpose

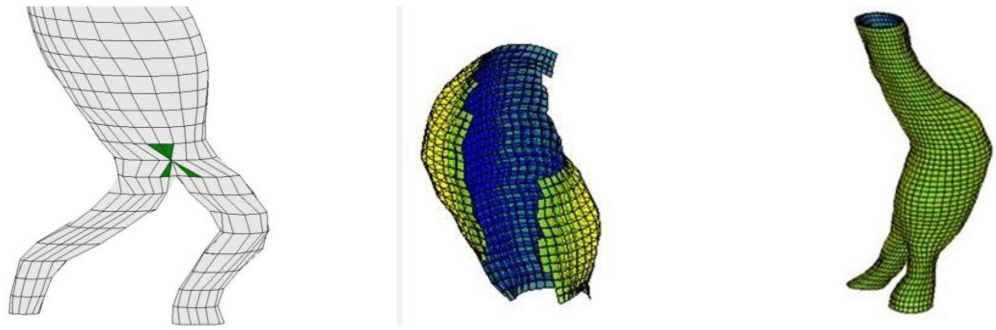
To propose an automated patient-specific algorithm for the creation of accurate and smooth meshes of the aortic anatomy, to be used for evaluating rupture risk factors of abdominal aortic aneurysms (AAA). Finite element (FE) analyses and simulations require meshes to be smooth and anatomically accurate, capturing both the artery wall and the intraluminal thrombus (ILT). The two main difficulties are the modeling of the arterial bifurcations, and of the ILT, which has an arbitrary shape that is conforming to the aortic wall.

## Methods

The method proposed constructs patient-specific meshes directly from 3D images composed of axial slices of the vessel, where lumen, wall and ILT are visible. The process consists of four steps: segmentation and classification of the image slices, computation of node locations, construction of hexahedra, and mesh smoothing. An additional post-processing step subdivides elements to maximize their quality and define the three anatomical layers of the walls and ILT.

Axial slices are classified according to the structures present: the abdominal aorta, the bifurcation, or the two iliac arteries. Mesh nodes are then placed in each slice at the contours of the structures, walls and ILT, with a set of criterions to ensure an even distribution through the ring shape of the axial cut of tubular structures. Mesh elements are then defined linking nodes from each pair of adjacent slices. Collapsed elements are taken to solve the geometrical challenge of modeling the bifurcation, where a single tubular structure (abdominal aorta) has to join with two tubular structures (iliac arteries) with different number of nodes. Fig.1 (a) shows the resulting reconstructed mesh with minimal distortion at the bifurcation. Finally, the mesh obtained is smoothed to avoid sharp edges caused by image segmentation errors and partial volume effects. The resulting mesh fulfills the requirements imposed by the simulation of the FE algorithms.

Anatomically, the aortic wall is made up of three layers, the intima, the media, and the adventitia. Moreover, three layers are generally present in ILT, luminal, medial and abluminal [1]. Accordingly, an additional post-processing step divides the aortic wall and the ILT area into three layers in the radial direction by taking empirical proportions: intima 0.19, media 0.44, and adventitia 0.37 [2]; luminal 0.38, medial 0.38, and abluminal 0.24 [3].



a) b) c)

**Fig. 1** Conforming hexahedral meshes of the aortic anatomy. (a) Collapsed hexahedra (in green) required for a soft transition at the bifurcation. (b) Elements corresponding to the ILT. (c) External surface of the smoothed model of the AAA.

## Results and discussion

The performance of the algorithm is evaluated using six MRI datasets of different patients. Patient-specific hexahedral mesh of two conforming structures, the aortic wall and the ILT, are constructed for each dataset.

Mesh resolution and accuracy depends on the available resolution of the initial image dataset. Results show an inverse relationship between the smoothness of the hexahedra and the required computation time. High-resolution models are obtained in less than ten seconds with code developed in Matlab 2009b. An example of a final meshes obtained is presented on Fig. 1 (b) and (c).

Vessel's sections which have not axial orientation are poorly approximated using linear interpolation. Results are even more degraded with wide slice thickness, or with tortous aortas. Future works will explore the extension of this work with the calculation of slices perpendicular to the centerline of the vessel.

## Conclusions

The developed algorithm generates two conforming hexahedral meshes, each composed of three different layers. Results illustrate the capability to model the variability of the aortic wall thickness and the distribution of the ILT within the aneurysm.

## References

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